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Jonkeren, O.E.; van Ommeren, J.N.; Rietveld, P.

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# Climate Change and Inland Waterway Transport

## Welfare Effects of Low Water Levels on the river Rhine

**Olaf Jonkeren, Piet Rietveld, and Jos van Ommeren**

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*Address for correspondence:* Olaf Jonkeren, Vrije Universiteit, FEWEB, De Boelelaan 1105, 1081 HV Amsterdam (ojonkeren@feweb.vu.nl). The authors are at the Department of Spatial Economics of the Vrije Universiteit, Amsterdam.

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### Abstract

The authors derive the annual welfare effects of low water levels on the river Rhine employing detailed trip data reported by bargemen between January 2003 and July 2005. They find a considerable effect of water levels on freight price *per ton* and load factor, but the effect on the price *per trip* is close to zero. Using water level information over a period of almost 20 years, the average annual welfare loss due to low water levels is estimated to be about €28 million. In years with extremely low water levels, such as in 2003, the loss amounts to about €91 million, about 13 per cent of the market turnover in the part of the Rhine market considered.

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## 1.0 Introduction

The summer of 2003 in Europe was probably the hottest since the 15th century, taking into account uncertainties in temperature reconstruction (Luterbacher *et al.*, 2004; Beniston, 2004). Under un-mitigated emissions (of greenhouse gasses) scenarios, summers like 2003 in Europe will probably be experienced more often in the future (Stott *et al.*, 2004).<sup>1</sup> After stabilisation of the emissions of greenhouse gasses, surface air temperature is projected to continue to rise for a century or more (IPCC, 2001).

Little attention has been given to the effect of changes in the natural environment on transport costs.<sup>2</sup> Such attention is relevant, however, because it may contribute to the formulation of policies to adapt to these changes (for example, de Groot *et al.*, 2006). Examples of the thin literature on the effects of climate change on transport can be found in Suarez *et al.* (2005) and Nankervis (1999). In addition, some literature exists on the effects of weather on safety in road transport (for example, Edwards, 1999; Brodsky and Hakkert, 1988).

The current study contributes to this literature as it focuses on the effect of climate change on social welfare through inland waterway transport. We concentrate on a part of the European inland waterway transport market, the river Rhine market. The river Rhine is the most important waterway in Europe. About 70 per cent of all inland waterway transport in the former EU-15 member states is transported on the Rhine.

The river Rhine is a combined rain–snow river. As a result of climate change, it is expected that the Rhine will be more rain-oriented in the future. More specifically, it is expected that in winter precipitation will increase and higher temperatures will cause a smaller proportion of precipitation to be stored in the form of snow in the Alps. As a result, in winter more precipitation will directly enter rivers, average water levels will be higher, and the number of days with low water levels will decrease. In summer, besides a reduction in melt water contribution, there will be less precipitation and more evaporation due to higher temperatures. As a consequence, inland waterway vessels on the Rhine will experience lower

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<sup>1</sup>Global warming, especially in the second half of the 20th century, can be explained by an increase of greenhouse gases in the atmosphere with a negligible contribution from natural forcings (Stott *et al.*, 2004; Tett *et al.*, 2002; Mann *et al.*, 1998).

<sup>2</sup>In contrast, a substantial number of studies have examined the effects of transport on environmental costs. We mention, for example, Johansson-Stenman (2006) and Button and Verhoef (1998) for road transport, Cushing-Daniels and Murray (2005) and Brons *et al.* (2003) for rail transport, Schipper (2004) and Carlsson (2002) for air transport, and Eyre *et al.* (1997), Nordhaus (1991) and Button (1990) for transport in general.

water levels as well as an increase in the number of days with low water levels in summer and autumn (Middelkoop *et al.*, 2000; 2001). The current paper starts with the observation that low water levels occur more often and have more severe impacts than high water levels, so it concentrates only on the consequences of low water levels on the economy.

We estimate the size of the welfare loss due to low water levels at a specific location, employing data for the inland waterway transport spot market. Low water levels imply restrictions on the load factor of inland waterway vessels. As a consequence the costs per ton, and thus also the price per ton transported, will rise. To be more specific, we determine to what extent higher prices per ton emerge when the water level drops below a certain threshold, implying additional transport costs for the economy in times of low water levels. Note that there are some other welfare effects as a result of low water levels that are ignored here. For instance, shippers may suffer from low water levels due to unreliability of delivery.

We focus on water levels at a particular location along the Rhine in Germany called Kaub. Although for some of the trips that pass Kaub the maximum load factor may be determined by water levels in tributaries of the Rhine, for the large majority of the trips that pass Kaub, the water depth at Kaub is the bottleneck. The estimated size of the welfare loss thus concerns cargo that is transported via Kaub during low water levels. Figure 1 shows the location of Kaub.

In Germany the navigability of the Rhine is measured by the 'Pegelstand' or 'Pegel'. Pegelstand is related to actual water depth. There are several locations along the Rhine where the Pegelstand is measured. Each Pegel has its own 0-point. Thus, with Pegel Kaub it is only possible to determine navigation depth in the surroundings of Kaub. For other places, other Pegels are valid. The water depth at Kaub exceeds the Pegelstand at Kaub by about 100 cm. So, at Pegel Kaub 90 cm there is about 190 cm water between soil and surface, the water depth. For the sake of convenience we will employ water depths in this paper and regard water depth and water level as synonymous.

Estimation of the welfare loss is based on the effect of water levels on freight prices *per ton* observed during the period from the beginning of 2003 to July 2005. In addition, we assess the effects of water level on load factor and price *per trip*. Using the latter effect, we are able to demonstrate that the inland waterway transport market can be considered as a competitive market with perfectly elastic supply. We estimate the annual welfare loss for the period between 1986 and 2004. We pay special attention to the year 2003 because this year was an extreme year with respect to low water levels and indicative for what might occur more often in the future.

**Figure 1**  
*Location of Kaub (Germany) at the river Rhine*



The purpose of this paper is to contribute to the knowledge about the effects of climate change on the economy. Given the welfare loss of low water levels, one is able to examine whether investment in projects that aim to make inland waterway transport more robust to low water levels might be economically sound.

In the next section, the theory concerning welfare implications of low water levels and competitive markets will be briefly addressed, as it is quite standard. Section 3 deals with the data we use for our research, and in Section 4 the results will be presented. In Section 5 we conduct the welfare analysis, and Section 6 offers some concluding remarks.

**2.0 Theory**

Our estimation of the welfare loss is based on two assumptions: perfect competition in the long run and perfectly elastic supply.

The inland waterway transport market, and in particular the Rhine market, may be characterised as a competitive market: inland waterway transport enterprises offer an almost homogeneous product (transport of different types of bulk goods), there are many suppliers, shippers may

easily switch from one inland waterway transport enterprise to another and it is relatively simple to enter the Rhine market out of other adjacent geographical markets. Also Bongaerts and van Schaik (1984) describe the inland waterway transport market as a competitive market. In the short run, inland waterway transport enterprises may generate positive profits, but this lasts only for a short period of time.

The assumption of perfectly elastic supply seems reasonable since entry is not limited, even in the short run, due to movements of inland waterway vessels between distinct geographical markets. Also, firms are fairly equal and input prices, such as fuel, are likely to be constant as output increases.

Note that one may argue that in reality inland waterway vessels are not equal in terms of size (see also Table 1). Large ships enjoy economies of vessel size and operate in the market segment for large shipments (that is, more than 2,500 tons). However, large ships are not able to underprice small ships, because small ships operate in the market segment for small shipments. Due to the heterogeneity in demand concerning shipment size, different markets exist at the same time. Consequently, within each segment, it is reasonable to assume a horizontal supply curve.

Because the inland waterway transport market can be described as a market with perfect competition and perfectly elastic supply, the economic surplus equals the consumer surplus and the welfare loss due to low water levels equals the reduction in consumer surplus.<sup>3</sup> The assumption of perfectly elastic supply is of importance for the correct estimation of the welfare loss. If supply is inelastic, the size of the welfare loss would be larger than reported here.

Although the inland waterway transport sector does not directly serve a consumer market, the assumption of 'no market imperfections' implies that the change of economic surplus in the inland waterway transport market is equal to the change in the consumer surplus in the market of the transported goods (Lakshmanan *et al.*, 2001).

The welfare effect will be determined on basis of the observed price per ton,  $p$ . The price per ton includes costs such as interest, labour, fuel costs, handling costs, and so on. The quantity transported is denoted by  $q$ . Note that under the assumption of perfect competition, the price per ton equals the costs per ton, ( $p = c$ ) and the price per trip equals the costs per trip ( $P = C$ ). The load factor is denoted as  $\theta$ . We will now distinguish between a situation with normal water levels (situation 0) and low water levels (situation 1).

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<sup>3</sup>For theoretical considerations on perfect competition see studies by, for example, Stigler (1957) and Robinson (1934). In these studies several definitions and characteristics of (perfect) competition are discussed. Hausman (1981) and Willig (1976) address the concept of the economic surplus.

Ships operate with a  $\theta_0$  load factor if the water level exceeds a certain threshold level. When the water level drops below the threshold level, inland waterway vessels have to reduce their load factor from  $\theta_0$  to  $\theta_1$  to be able to navigate safely, so  $\theta_1 < \theta_0$ . As a result the costs of shipment per ton at low water levels are  $c_1 = c_0 \times \theta_0/\theta_1$ , so transport costs *per ton* are a factor  $\theta_0/\theta_1$  higher given low water levels. As a consequence inland waterway transport enterprises charge a higher price per ton and the economic surplus is reduced. The welfare loss due to low water levels can be approximated by the following equation:

$$WL = (p_1 - p_0)q_0(1 + \frac{1}{2}\varepsilon(p_1 - p_0)/p_0), \quad (1)$$

where  $\varepsilon$  is the price elasticity of demand

$$\varepsilon = [(q_0 - q_1)/q_0]/[(p_0 - p_1)/p_0]. \quad (2)$$

In the empirical analysis the annual welfare loss will be based on (1). In that case  $q_0$  is the number of days with low water levels multiplied by the average daily quantity transported during normal water levels. We will show later on that the price per trip at normal water levels is equal to the price per trip at low water levels,  $P_0 = P_1$ , which implies that  $C_1 = C_0$ , so the transport costs per trip do not depend on the water level.<sup>4</sup> This finding is consistent with our assumption that supply is perfectly elastic.<sup>5</sup> In addition, it is a strong indication for the existence of perfect competition in the inland waterway transport market.

### 3.0 Dataset and Methodology

#### 3.1 Data

We employ a unique dataset, the Vaart!Vrachttindicator, which contains detailed information about trips made by inland waterway transport enterprises in Western Europe.<sup>6</sup> The enterprises report information via internet

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<sup>4</sup>Note that it may be argued that in reality fuel consumption decreases as the water level drops. However, because fuel costs are only about 20–25 per cent of the total costs, the costs of a trip with a low load factor is only slightly reduced. A compensating factor is that other costs rise in periods of low water levels, as is mentioned in RIZA *et al.* (2005). They mention longer waiting times at locks and extra handling as a cause for extra costs in periods of low water levels.

<sup>5</sup>Perfectly elastic supply means that firms supply as much as the market wants as long as the price covers the costs of production. This can only occur in markets with perfect competition or monopolistic competition with many firms. Horizontal supply curves may also occur in monopolistic or oligopolistic markets. However, in these market forms firms are price setters and do not supply as much as the market wants.

<sup>6</sup>More information can be found on the website [www.vaart.nl](http://www.vaart.nl).



**Table 1**  
*Distribution of Vessels over Tonnage Classes*

<i>Vessel size</i>	<i>Kaub dataset</i>
0–649 tons	2.8%
650–999 tons	12.2%
1,000–1,499 tons	31.9%
1,500–1,999 tons	20.5%
2,000–2,499 tons	11.4%
>2,500 ton	21.3%

The results are based on data from the Vaart!Vrachttindicator (2003–2005).

about their trips such as the price per ton, place and date of loading, place and date of unloading, capacity of the ship, number of tons transported, type of cargo, and so on. Although the dataset contains repeated information for some enterprises, the data cannot be characterised as trip panel data. Enterprises only accidentally make the same trip, so our sample can be best viewed as repeated cross-section data. The dataset contains information on inland waterway transport enterprises that operate in the spot market where the price per ton, and the number of tons transported are negotiated for each trip. Inland waterway transport enterprises that operate in the long-term market (and work under contract) and receive a fixed price per ton throughout the year are not included in the dataset.

The database contains 8,946 observations of trips, reported between the beginning of 2003 and July 2005. We exclude all trips that do not pass Kaub (6,059 observations), which means we have 2,889 remaining trips as vessels that pass Kaub are particularly restricted in their load factor. Then we exclude a relatively small number of trips (25 observations) referring to container transport since its unit of measurement is volume whereas other products are measured in tons. So we have 2,864 remaining trips suitable for analysis.

Table 1 shows the distribution of the vessel sizes in the Kaub dataset. The Kaub market is dominated by vessels between 1,000 and 2,000 tons. The average capacity of the fleet in the Kaub-dataset is 1,776 tons.

**3.2 Descriptives**

The descriptives of the key variables, price per ton, load factor, price per trip and water level, which play a major role in the theoretical section, are given in Table 2 and Figure 2. In Table 2 we distinguish between trip and day observations.

The latter are obtained by taking averages of several trips over a day. We have about 750 valid day observations. The mean price per ton is



**Table 2**  
*Descriptives of Key Variables*

<i>Variable</i>	<i>No. of observations (day data)</i>	<i>No. of observations (trip data)</i>	<i>Minimum (trip data)</i>	<i>Maximum (trip data)</i>	<i>Mean (trip data)</i>	<i>Std. deviation (trip data)</i>
Water level (Kaub) in cm	903	2,849	135.00	780.00	192.66	79.57
Price per ton (in €)	773	2,847	1.80	52.00	8.56	5.39
Load factor (in %)	745	2,530	0.10	1.01	0.78	0.17
Price per trip (in €)	759	2,586	1,036.55	71,000.00	9,810.82	5,571.08

The results are based on data from the Vaart!Vrachindicator (2003–2005).

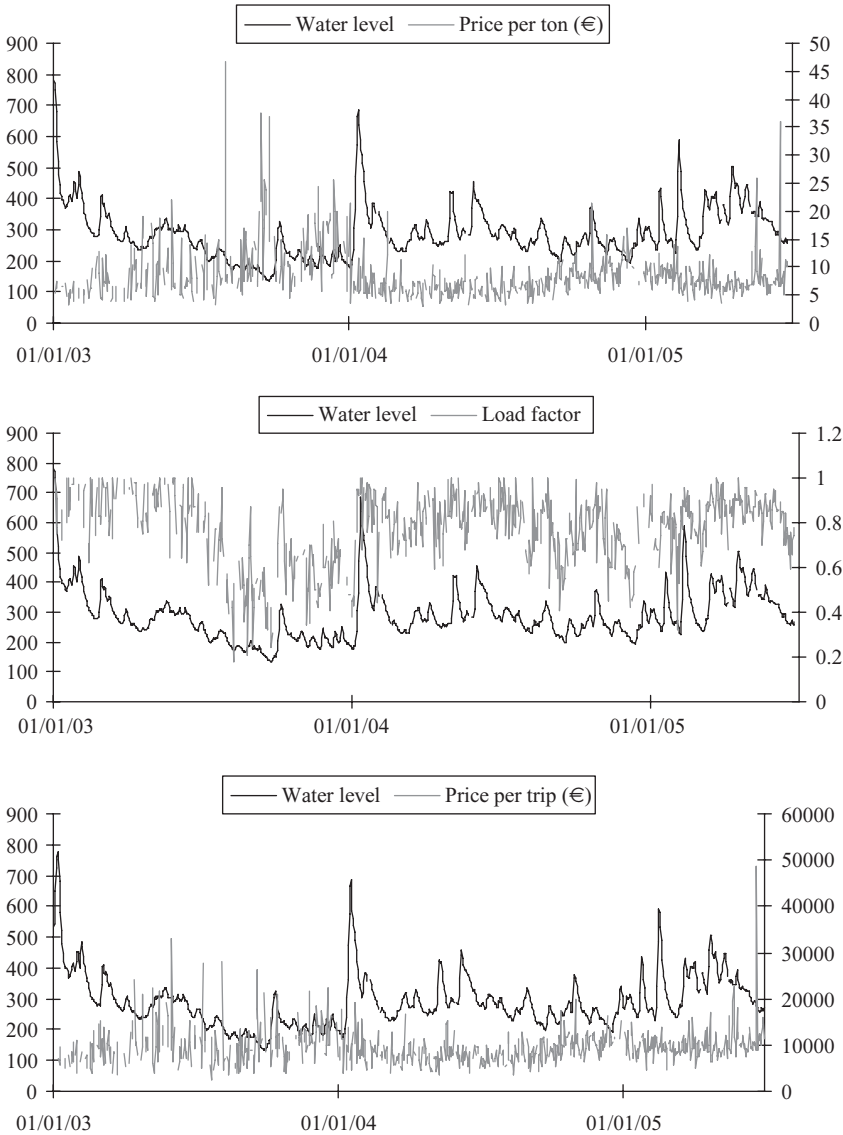
about €8.50 and the mean load factor is 0.78. Figure 2 shows the water level variation over a 2.5 year period. Particularly in the second half of 2003, water levels were below 260 cm at Kaub, which will be identified later on as the threshold level for low water levels. There is clearly a seasonal pattern (for example, in late summer, water levels are low). Note that there is still sufficient variation *within* months to identify a separate effect of water level controlling for monthly variation.

The figure shows a strong negative relationship between the price per ton and water level. For example, in September 2003 water levels were exceptionally low and prices per ton were exceptionally high. Furthermore, there is a positive relationship between water level and load factor, in line with theoretical considerations: as the water level drops, the load factor drops. Finally, the figure does not show a clear relationship between water level and price per trip. Note that also this finding is in line with the assumption of a competitive market. In the next section, we will examine these relationships using multivariate techniques.

**4.0 Multiple Regression Analysis**

We assess the impact of water level on the logarithms of freight price per ton, load factor and price per trip using a regression analysis. We use the following explanatory variables in each regression: a time trend; trip distance in logarithm (see McCann, 2001); ship size (4 dummy variables), which allows for economies of vessel size; cargo type (41 dummy variables), because of differences in the mass per volume of each cargo type; and

**Figure 2**  
*Relation between Water Level and Price Per Ton, Load Factor and Price Per Trip*



Source: The Vaart!Vrachtingindicator (2003–2005).

navigation direction, to correct for backhaul and because for upstream navigation more fuel is needed than for downstream navigation. Fuel price is not taken up as an explanatory variable as it highly correlates with the time trend.

The following additional two explanatory variables need extra attention. The water level variable is measured by means of nine dummy variables to allow for a flexible functional form of this variable. Each dummy represents a water level interval of 10 cm. The reference-category is the group where water levels exceed 260 cm, which measures the threshold level. We have performed a sensitivity analysis and it appears that the effect of water level is absent when water levels exceed 260 cm at Kaub.

We included a dummy variable for each month (29 dummies) to control for unobserved monthly changes in supply and demand factors. The estimated effect of water level is then unlikely to be spurious because unobserved changes in demand and supply factors within short periods such as a month are likely to be small. In addition, unobserved changes that occur within a short period are unlikely to be correlated with water level. Note that the choice of the number of the time dummies (for example, weekly, monthly, seasonal) affects the estimated effect of water level. The more time dummy variables, the less likely it is that the estimated effect is spurious. The consequence is, however, that some variation in the dependent variable may not be attributed to the effect of water level as it is captured by the time dummies. Therefore the water level effects may be somewhat underestimated.

One may analyse the data at the level of trips or days. Both analyses have their advantages. Employing the day average data enables us to model serial correlation of (unobserved components of) the dependent variables using regression models with lagged variables. The disadvantage of such an approach, however, is that by employing day averages, information on variation of variables within the same day is ignored. Using the trip data, it is straightforward to control for factors that refer to a specific trip (for instance, the distance). The drawback of the trip data is that modelling correlation of unobserved factors between and within days is less straightforward. It is not clear whether the analysis of one data type is superior to the other. It turns out, however, that the results of both data types generate very similar results. Tables 3 and 4 show the estimated coefficients for both trip and day data.

To examine the validity of our regression models we performed diagnostic tests to check serial correlation and heteroskedasticity. Based on such analysis we transformed the dependent variables by taking the natural logarithm to reduce heteroskedasticity. Scatter plots show that, after this transformation, the variance of the residuals is close to constant.

Three tests, employing the *day data*, indicate that serial correlation of the residuals is present in the regressions with load factor and price per trip as dependent variables but not in case of the dependent variable

price per ton. We employ the Ljung–Box test (or Q-statistic), the Durbin–Watson test, which is only indicative due to missing values (Gujarati, 2003), and we test if the (partial) correlations differ significantly from zero. To eliminate the serial correlation, we estimate several regression models with lagged values of the concerning explained variables. On the basis of information criteria (AIC and SIC) and LR-tests, models are selected. Evaluation of these criteria on the different models is shown in Appendix A.

The best models turned out to be those with one lagged value in the case of the model with dependent variable price per trip and two lagged values in the case of the model with dependent variable load factor. The size of the two coefficients of the lagged load factors are 0.13 (AR1) and 0.11 (AR2) and the value of the coefficient of the lagged price per trip is  $-0.17$  (AR1). Why the latter value is negative remains a bit of a puzzle. Because the sum of the absolute value of the AR-coefficients is smaller than 1 in both AR processes, these processes are stationary.

Our main result is that the water level has a strong, statistically significant, negative effect on the price per ton, a strong positive effect on the load factor, and no (systematic) effect on the price per trip. These results are the basis of the welfare analysis in the next section. The latter finding indicates that the inland waterway transport market is a competitive market as assumed in the theoretical section. Bishop and Thompson (1992) apply a similar approach to show that their theoretical assumption of a competitive market is plausible.

By definition, the price per trip is equal to the price per ton times the number of tons transported. Hence, when trip prices do not depend on water levels, the sum of the effects of water levels on the logarithm of price per ton and the logarithm of load factor will be zero, controlling for the vessel size. This is confirmed by our results.

The results are also in line with figures derived from the IVTB (VBW, 1999). This document determines rights and obligations of inland waterway transport enterprises and shippers in the European market. It serves as a kind of guideline for both parties for setting up short- and long-term contracts and for low water surcharges that can be used in negotiations. The IVTB state that usually at 250 or 240 cm water level at Kaub low water surcharges can be charged.

The effect of water level on the price per ton is the opposite of the effect on load factor. Note that the drop in load factor, as presented in Tables 3 and 4, is relative to the situation of ‘normal’ water levels, which we defined as water levels higher than 260 cm at Kaub.

Given normal water levels, the average load factor is 84 per cent. The drop in load factor has to be regarded relative to this percentage. In Table 5 we derived the average prices per ton, load factors and prices per

**Table 3**  
*Estimation Results for Trip Data*

	Price per ton		Load factor		Price per trip	
Variable	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Water level, 9 dummies						
>261			Reference category			
251–260	0.029	0.023	−0.065	0.018	−0.022	0.024
241–250	0.088	0.025	−0.137	0.019	−0.003	0.027
231–240	0.075	0.021	−0.125	0.017	−0.048	0.023
221–230	0.146	0.026	−0.170	0.021	−0.005	0.028
211–220	0.156	0.030	−0.244	0.023	−0.074	0.032
201–210	0.225	0.040	−0.287	0.034	−0.031	0.045
191–200	0.316	0.035	−0.367	0.028	−0.024	0.039
181–190	0.289	0.037	−0.464	0.032	−0.180	0.042
≤ 180	0.553	0.036	−0.529	0.031	0.058	0.041
Distance log(kilometres)	0.501	0.016	0.010	0.013	0.536	0.017
Vessel size, 4 dummies						
0–1,000 tons	0.253	0.017	0.240	0.013	−0.744	0.018
1,000–1,500 tons	0.117	0.012	0.223	0.011	−0.444	0.014
1,500–2,000 tons	0.080	0.014	0.128	0.011	−0.292	0.015
2,000–2,500 tons	0.038	0.019	0.092	0.015	−0.092	0.020
>2,500 tons			Reference category			
Navigation direction, and backhaul						
Trips upstream on Rhine	0.323	0.015	0.009	0.012	0.310	0.016
Trips upstream on Rhine, to Danube	0.596	0.028	0.011	0.022	0.524	0.031
Trips downstream on Rhine, from Danube	0.224	0.029	−0.068	0.024	0.186	0.033
Trips downstream on Rhine			Reference category			
Cargo type, 41 dummies	Included	–	Included	–	Included	–
Time trend, divided by 1000	0.378	0.192	0.062	0.149	0.735	0.208
Time dummies, 29 months	Included	–	Included	–	Included	–
Model performance						
R <sup>2</sup>	0.79		0.59		0.76	

The results are based on data from the Vaart!Vrachindicator (2003–2005). The dependent variables are measured in logarithm.

trip for an average ship at the different water level intervals based on the estimates reported in Table 3. We see that in the lowest water level interval an average ship uses less than 50 per cent of its capacity. The estimated effect on the price per ton more or less offsets the reduction in load factor, as we can see in the column for price per trip.

We will briefly discuss the effect of the control variables. We find that distance has a positive effect on price per ton and price per trip but does not affect the load factor. The effect of vessel size on price per ton decreases as the vessel size increases, which suggests the existence of economies of

**Table 4**  
*Estimation Results for Day Data*

	Price per ton		Load factor		Price per trip	
Variable	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
<b>Water level, 9 dummies</b>						
>261			Reference category			
251–260	0.040	0.030	−0.040	0.026	0.019	0.034
241–250	0.122	0.034	−0.146	0.030	0.015	0.038
231–240	0.089	0.032	−0.153	0.030	−0.083	0.036
221–230	0.145	0.038	−0.153	0.036	−0.035	0.042
211–220	0.209	0.041	−0.268	0.038	−0.080	0.045
201–210	0.293	0.050	−0.351	0.046	0.036	0.057
191–200	0.337	0.050	−0.416	0.047	−0.055	0.055
181–190	0.316	0.048	−0.467	0.047	−0.238	0.054
≤ 180	0.505	0.051	−0.541	0.051	0.008	0.057
<b>Distance log(kilometres)</b>	0.431	0.037	−0.028	0.031	0.469	0.045
<b>Vessel size, 4 dummies</b>						
0–1,000 tons	0.241	0.038	0.229	0.032	−0.632	0.045
1,000–1,500 tons	0.120	0.028	0.251	0.024	−0.297	0.034
1,500–2,000 tons	0.068	0.030	0.124	0.026	−0.152	0.037
2,000–2,500 tons	0.019	0.051	0.083	0.042	0.010	0.061
>2,500 tons			Reference category			
<b>Navigation direction, and backhaul</b>						
Trips upstream on Rhine	0.307	0.034	0.079	0.029	0.286	0.041
Trips upstream on Rhine, to Danube	0.722	0.072	0.125	0.060	0.642	0.085
Trips downstream on Rhine, from Danube	0.173	0.061	−0.033	0.053	0.159	0.073
Trips downstream on Rhine			Reference category			
<b>Cargo type, 41 dummies</b>	Included		Included		Included	
<b>Time trend, divided by 1000</b>	0.241	0.286	0.006	0.977	0.518	0.335
<b>Time dummies, 29 months</b>	Included		Included		Included	
<b>Lagged values dependent variable</b>						
AR1			0.128	0.045	−0.169	0.041
AR2			0.109	0.044		
<b>Model performance</b>						
R <sup>2</sup>	0.83					
Log likelihood			−2,993.02		−3,323.58	

The results are based on data from the Vaart!Vrachtingindicator (2003–2005). The dependent variables are measured in logarithm.

vessel size in inland waterway transport. As discussed in Section 2, this is not inconsistent with the assumption of perfectly elastic supply. Further, the coefficients indicate that smaller inland waterway vessels navigate with higher load factors. The trip data show that the time trend has a slightly positive effect on the price per ton and price per trip while there is no increase in load factor over time. The day data show no significant

**Table 5**  
*Estimated Prices Per Ton, Load Factors and Prices Per Trip*

<i>Water depth Kaub (cm)</i>	<i>Estimated price per ton in € (trip data)</i>	<i>Estimated load factor (trip data)</i>	<i>Estimated price per trip in € (trip data)</i>
>260	7.53	84%	9,626
251–260	7.75	78.8%	9,414
241–250	8.22	73.2%	9,597
231–240	8.11	74.1%	9,173
221–230	8.71	70.9%	9,577
211–220	8.80	65.8%	8,943
201–210	9.43	63.0%	9,337
191–200	10.33	58.2%	9,395
181–190	10.05	52.8%	8,037
≤ 180	13.09	49.5%	10,193

The results are based on data from the Vaart!Vrachindicator (2003–2005).

effect of the trend at all. The variable that controls for navigation direction and backhaul indicates that trips upstream on the Rhine with destinations at the Danube have a relatively large increase in price per ton and price per trip. The explanation is the longer duration of the trip: in particular inland vessels that navigate to and from the Danube have to pass many locks.

Because it is plausible that the change in the dependent variables for large ships is larger than for small ships when the water level drops, as smaller ships are less affected by low water levels, we test for the presence of an interaction effect between the water level and the size of the ship. Water level is measured as a continuous variable and ship size is measured as a continuous logarithmic variable. Above a certain water level, it is plausible that the marginal effect of water level on the load factor and therefore on the price per ton is zero because the load factor is at its maximum. Water level values above 260 cm are therefore fixed at 260 cm, in line with findings reported in Tables 3 and 4.

Let us define  $\alpha$  as the logarithm of the vessel size in tons. The marginal effect of water level on the logarithmic price per ton is equal to  $0.004113 - 0.001330\alpha$ , on the logarithmic load factor  $-0.010294 + 0.002221\alpha$  and on the logarithmic price per trip  $-0.011687 + 0.001597\alpha$ . Table 6 gives the marginal effects of water level for several ship sizes. Given a *decrease* in water level, for small ships, the increase in price per ton is less than for large ships. For large ships the increase in price per ton less than offsets the reduction in load factor while for small ships we observe the opposite. Therefore, given a decrease in water level, the price per trip decreases for large ships but increases for small ships. Observing Table 6, a decrease of water level of one centimetre leads to an increase of 0.654 per cent of the price per ton for vessels of 3,000 tons. For a ship



**Table 6**  
*Marginal Effect of Water Level on Dependent Variables*

Dependent variable in logarithm	Ship size (in tons)			
	500	1,000	3,000	5,000
Price per ton	−0.00415	−0.00507	−0.00654	−0.00721
Load factor	0.00351	0.00505	0.00749	0.00862
Price per trip	−0.00176	−0.00066	0.00110	0.00191

The results are based on data from the Vaart!Vrachindicator (2003–2005).

size of 1,507 tons, the increase in price per ton exactly offsets the reduction in load factor. The interaction effects will be ignored in the welfare analysis as these are secondary.

Another potentially important aspect we address is the time lag between the moment of reporting a trip and the moment of passing Kaub by a ship. Usually one or two days are in between those moments. We have investigated what the effect of forecast water levels is on the dependent variables. If we re-estimate the same model as in Table 4, but measuring the water level variable as a continuous variable, measuring values above 260 cm as 260 cm and we also include the first, second, or both leading values of the water level variable, we find results as summarised in Table 7. The results in Table 7 suggest that bargemen take into account future water levels when determining the load factor of their ships in periods of low water levels.

However, future water levels do not seem to play a role in determining the price per ton. We find that the total effect of water level (the sum of the

**Table 7**  
*Significance of Coefficients for Lead Values of Water Level at the 5 Per Cent Level*

Dependent variable	Water level	Water level + 1st lead value of water level		Water level + 2nd lead value of water level		Water level + 1st + 2nd lead value of water level		
		Water level	1st lead value	Water level	2nd lead value	Water level	1st lead value	2nd lead value
Price per ton	Sign.	Sign.	Insign.	Sign.	Insign.	Sign.	Insign.	Insign.
Load factor	Sign.	Sign.	Sign.	Sign.	Sign.	Sign.	Insign.	Sign.
Price per trip	Insign.	Insign.	Insign.	Insign.	Insign.	Insign.	Insign.	Insign.

The results are based on data from the Vaart!Vrachindicator (2003–2005).

different water level effects) in the estimations underlying Table 7 is about the same as in Tables 3 and 4. This finding makes sense considering the high correlations between water level and its first (0.98) and second (0.94) lead value.

The selection mentioned in subsection 3.1 implies that our estimate of the welfare loss only refers to trips passing the bottleneck Kaub. Trips that do not pass Kaub encounter other low-water bottlenecks that impose less severe restrictions on the load factor of inland ships and thus have a weaker effect on the freight price per ton. Furthermore, in non-Kaub areas, freight prices per ton might be indirectly affected by water level restrictions at Kaub in the short run, because the demand for ships in the Kaub market will attract inland ships from the non-Kaub markets. We have estimated similar models as in this paper for areas where low water levels are less severe (the canals in North Germany). Although the number of observations is limited, it appears that a smaller (but statistically significant) effect of water level at Kaub on the price per ton in North Germany can be observed.<sup>7</sup>

## 5.0 Welfare Analysis

We use equation (1) to estimate the welfare loss in the years 1986 to 2004. For this period we have daily water levels at Kaub and the annual transported quantity via Kaub at our disposal. The value of  $q_0$  is based on yearly aggregate data (CCNR, 1998; 2000; 2002; 2005 and PINE, 2004) presented in Appendix B (Table 11), presuming that  $q_0$  is large as the number of days with water levels below 260 cm at Kaub in a year is large.

Estimation of the prices  $p_0$  and  $p_1$  is based on the dataset that contains trips of inland waterway vessels between beginning 2003 and mid 2005. The average price per ton of all trips made at normal water levels is €7.53 and at low water levels €9.39. The coefficients in Table 3 (trip data) are used to calculate the price increase at each water level interval.

Estimates of the price elasticity of demand ( $\epsilon$ ) for inland waterway transport are mainly found in North-American literature. Table 8 gives an overview. The estimates found in the literature concern yearly price elasticities of demand for inland waterway transport and have a median value of about  $-1.0$ . For a number of reasons it is plausible that demand for inland waterway transport may be more inelastic. First, the price for

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<sup>7</sup>Note that we do not have the water levels in these canals at our disposal, but it is likely that these water levels strongly correlate with the water level at Kaub.

Table 8

Literature on Price Elasticities of Demand in Inland Waterway Transport

Paper	Estimated elasticity	Details
Yu and Fuller (2003)	[−0.5, −0.2]	Concerns grain transport, −0.5 for the Mississippi River and −0.2 for Illinois River
Dager <i>et al.</i> (2005)	[−0.7, −0.3]	Concerns corn shipments on Mississippi and Illinois Rivers
Oum (1979)	−0.7	Intercity freight transport in Canada for period 1945–1970
Train and Wilson (2005)	[−1.4, −0.7]	Revealed and stated preference data to analyse both mode and O-D changes as a result of an increase in the barge rate for grain shipments
Henrickson and Wilson (2005)	[−1.9, −1.4]	Concerns grain transport on Mississippi and accounts for spatial characteristics of the shippers
Beuthe <i>et al.</i> (2001)	[−10.0, −0.2]	Estimated elasticities for 10 different commodities of cargo based on a multimodal network model of Belgian freight transports

transport by inland waterway vessel for most bulk goods is substantially lower than transport by another mode. Consequently, the price per ton has to rise substantially before other transport modes become competitive and modal shift effects are expected to be small. Second, inland waterway vessels transport such large quantities that other modes of transport do not have nearly enough capacity to transport all cargo originally transported by inland waterway vessels. Third, and more fundamentally, shippers aim to prevent their production process from costly interruptions and costs of inland waterway transport are only a small part of total production costs. Harris (1997) mentions that for most low value goods, such as coal and steel, inland waterway transport is about 2 per cent of total production costs. Thus, paying more for inland waterway transport in periods of low water levels is more cost-effective than having interruptions in the production process. So, demand for inland waterway transport is thought to be more inelastic in the long run (measured in weeks). In the short-run (measured in days) the demand may be more elastic because shippers are able to postpone transport and rely on their stocks, for example.<sup>8</sup>

To examine the short-run demand elasticity for inland waterway transport, we estimate the demand elasticity using daily data and a standard instrument variable approach. Hence, we regress the logarithm of the

<sup>8</sup>In the very long run (that is, decades), it is likely that demand will be more elastic, as shippers may shift location.

*daily* quantity transported on the logarithm of the *daily* price per ton controlling for a number of explanatory variables. A Hausman test showed that the logarithm of the daily price per ton is endogenous. In one regression we employ water level as an instrument and in another regression we employ water level *and* distance as instruments. It is very probable that the water level variable instrument is valid, because it is exogenous, will strongly affect the transport costs and consequently the supply function, and will *not* directly affect the demand for freight. If we only use water level as an instrument we are not able to test the validity of this instrument. The drawback of the instrumental variable analysis with two instruments, however, is that the validity of the instrument distance is somewhat questionable. A Sargan test shows that water level and distance together are valid instruments. Distance is also likely to be valid as an instrument, as it is not clear there is any systematic relation with temporal variations in quantity, whereas it has a direct and strong effect on the price. The validity of the instruments is empirically confirmed. We have experimented with a range of control variables, and the results are quite insensitive to the inclusion of control variables.

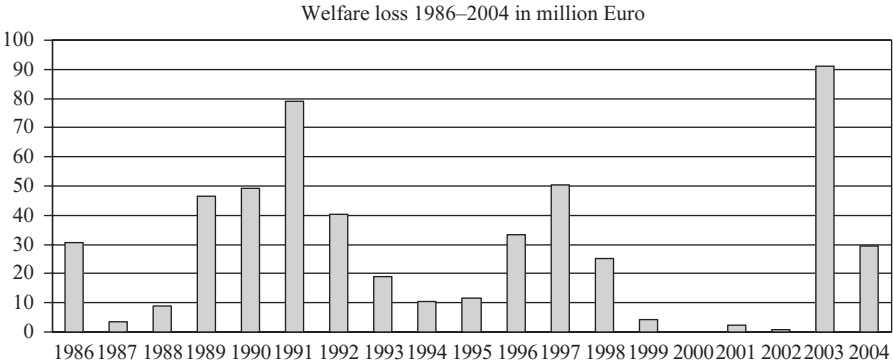
When we include as control variables a trend variable (to control for a trend in the number of observations in the survey), 11 month dummies (to control for seasonal variation due to monthly changes in demand and supply) and the logarithm of the size of the inland waterway vessels, we find that the point estimate of the demand elasticity is equal to  $-0.60$  with a standard error equal to  $0.27$  for the model with one instrument. Re-estimating the same model, but now with two instruments gives a demand elasticity equal to  $-0.40$  with a standard error equal to  $0.13$ . Statistically the  $-0.60$  and  $-0.40$  estimates are equal. Not controlling for the size of the inland waterway vessels, the demand is only slightly more elastic. Figure 3 shows the annual welfare loss for the period 1986 to 2004 using an elasticity of  $-0.6$ .

The current study is the first to focus on freight prices in inland waterway transport in relation to water levels. The estimated average annual welfare loss is €28 million in the period under investigation. In a few specific years the welfare loss was relatively high. In 2003 the loss amounted to €91 million, and in 1991 the welfare loss was also considerable at €79 million. Compared to the turnover in the Kaub related Rhine market of about €680 million the welfare loss in 2003 is about 13 per cent.<sup>9</sup> Our results are in line with another study which uses a different methodology.

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<sup>9</sup>The annual amount of cargo transported through the Kaub related Rhine market is about 80 million tons. The average price per ton for all journeys in the dataset that pass Kaub is about €8.50.

**Figure 3**  
*Welfare Loss due to Low Water Levels affecting Inland Waterway Transport via Kaub*



The results are based on data from the Vaart!Vrachtingindicator and CCNR, 2000; 2002; 2005.

RIZA *et al.* (2005) estimated the costs of low water levels for domestic inland waterway transport in the Netherlands based on assumptions about additional costs of low water levels. These extra costs concern the increase in the number of trips, in handling costs and costs as a result of longer waiting times at the locks and amounted to €111 million for the year 2003. The annual amount transported in the Dutch domestic market (100 million tons) is comparable to that of the Kaub related market (80 million tons). Other attempts to estimate the costs for inland waterway transport due to low water levels can be found in Millerd (2005) and Marchand *et al.* (1988). They use simulation models that minimise inland waterway transport costs on the Great Lakes in North America. We emphasise that the current study is based on observed prices in the market and not on difficult to observe costs.

Our welfare analysis is based on the assumption that the demand elasticity is  $-0.6$  (in line with our point estimate). Because one may argue that this assumption is inaccurate, we also estimated the welfare loss for another value of  $\epsilon$ . If we had used an elasticity of  $-1.0$ , the welfare loss would have been only 11 per cent less and amount to €81 million. This indicates that the size of the welfare loss is rather insensitive to the chosen elasticity.

Note that the estimated welfare loss is likely to be a minimum. Due to the large number of time dummies, the estimated water level effect may be somewhat underestimated, as argued above. As a sensitivity analysis we have reduced the number of time dummies. If we employ nine seasonal time dummies in our regression the welfare loss amounts to €113 million, and if we employ no time dummies at all the welfare loss leads to a welfare

loss of €146 million in 2003. Hence, the welfare loss in 2003 is somewhere between €81 and €146 million.

Another possible cause for the underestimation of the welfare loss may be that we control for distance. Controlling for distance implies that the separate effect of detour-kilometres as a result of low water levels on prices is ignored. However, regressing distance on water level and a range of control variables indicated an insignificant, and even positive, effect of water level on the trip distance, so that it is unlikely that detour-kilometres add to the costs during periods of low water levels.

Also, note that the welfare loss cannot be assigned to a certain geographical area, because the welfare loss is caused by all trips that pass Kaub. These trips have origins and destinations all over North-Western Europe. This also implies that there are other locations at the Rhine where welfare losses occur.<sup>10</sup> So the welfare loss estimated in this study concerns the Kaub related Rhine market, which is only part of a larger welfare loss related to the total Rhine market.

One reason why the estimated welfare loss may be an overestimation is that we do not have full insight into the number of trips of the inland ships, which means that the absence of a producer surplus is not guaranteed. It may be the case that in periods with low water levels, inland ships make more trips than in periods with normal water levels due to less waiting and (un)loading time or less empty trips. Given the presence of fixed costs (for example, interest on capital), there are profits in years with many days with seriously low water levels.<sup>11</sup> This implies the existence of a positive producer surplus that reduces the welfare loss presented here. In an empirical analysis not shown here, it appears, however, that the number of empty kilometres does not relate to low water levels. We do not have information about waiting and loading times so the impact of these factors cannot be analysed.

In the introduction it was mentioned that estimating the annual welfare loss of low water levels can give an indication as to whether investment in projects that aim to make inland waterway transport more robust to low water levels is economically sound. We estimate an average welfare loss of €28 million a year. This does not mean that investments to solve the low water level problem at Kaub may maximally cost €28 million a year. After all, if the bottleneck at Kaub is solved, there will be another location

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<sup>10</sup>For instance, inland waterway vessels that navigate from Rotterdam to Andernach, situated north of Kaub, may suffer from load factor restrictions caused at Cologne.

<sup>11</sup>In the long run (several years) profits are zero. But in a particular year profits may be positive or negative. Presumably, in years with many days with seriously low water levels, not enough inland ships enter the Kaub related inland waterway transport market to cut down the price per ton sufficiently, and thus the producer surplus is positive.

at the Rhine that determines the minimum load factor and that will cause a certain welfare loss.<sup>12</sup>

## 6.0 Conclusion

In this paper, we studied the effect of water level on freight prices per ton in inland waterway transport and consequently on welfare. For our estimation, several characteristics of inland waterway transport on the river Rhine were taken into account. The effect of water level on freight price per ton was found to be negative. The effect on the load factor was positive, and on the price per trip no effect was found. We derived an annual average welfare loss of €28 million due to low water levels on the river Rhine for the period of 1986 to 2004 for all waterway transports that passed the current bottleneck Kaub. The welfare loss in 2003 of €91 million was much higher due to a very dry summer. In the light of the observation that dry summers like that of 2003 are expected to occur more often in the future due to climate change, annual welfare losses as a result of low water levels via the inland waterway transport sector will rise.

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<sup>12</sup>This can be illustrated by an example. Suppose that if the load factor restrictions at Kaub are solved, Östlich is the next bottleneck. Assume that low water levels at Östlich cause an average annual welfare loss of €15 million. Then the investment to eliminate the welfare loss of €28 million caused at Kaub must be less than €13 million.



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Appendix A

Likelihood ratio-tests show that there is no difference in log likelihood between the model specifications. We choose the model with the lowest AIC (Akaike information criterion) and SIC (Schwarz information criterion). Then the model with one included AR term is preferred above the model with one AR and one MA term. Because the models with one AR and two AR terms are nested the AIC and SIC are weak criteria; however, the 2nd AR term is insignificant in the model with two AR terms so the model with AR(1) is the preferred model.

Likelihood ratio-tests show that the log likelihood of the model with two AR terms is significantly higher than the model with one AR term. The model with two AR terms shows a lower SIC and AIC than the model with one AR and one MA term so the model with AR(2) is the preferred model.

Table 9  
*Criteria for Models with Dependent Variable Price Per Trip*

<i>Lags included</i>	<i>AIC</i>	<i>SIC</i>	<i>Log likelihood</i>
AR(1)	6,827.15	7,243.80	−3,323.58
AR(2)	6,828.94	7,250.21	−3,323.47
ARMA(1,1)	6,828.58	7,249.85	−3,323.29

Table 10  
*Criteria for Models with Dependent Variable Load Factor*

<i>Lags included</i>	<i>AIC</i>	<i>SIC</i>	<i>Log likelihood</i>
AR(1)	6,171.52	6,586.48	−2,995.76
AR(2)	6,168.04	6,587.61	−2,993.02
ARMA(1,1)	6,168.84	6,588.41	−2,993.42

Appendix B

Table 11

*Annual Amount of Cargo that passes Kaub ( $\times 1,000$ )*

<i>Year</i>	<i>Tons along Kaub</i>
2004	83,527
2003	75,536
2002	85,917
2001	87,217
2000	87,456
1999	82,459
1998	84,866
1997	82,941
1996	79,642
1995	82,584
1994	82,844
1993	77,567
1992	81,466
1991	82,130
1990	84,635
1989	85,105
1988	82,673
1987	79,431
1986	81,052

*Source:* CCNR (1998, 2000, 2002, 2005); PINE (2004).

*Note:* The figures for 1986–1996 are approximated using an index for the transported annual amount of tons on the Rhine. The figures for 1997–2004 come from CCNR (1998, 2000, 2002).